aU

N91-28220

Space Transportation Propulsion
USSR Launcher Technology — 1990

June 1990

Rocketdyne — Advanced Programs
Special Programs Office
R. Jones, Program Manager

Rockwell International
Rocketdyne Division

AGENDA

- ENERGIA Background
  - Launch Vehicle Summary
  - Soviet Launcher Family
  - ENERGIA Propulsion Characteristics
- ENERGIA Propulsion Characteristics
  - Booster Propulsion
  - Core Propulsion
  - Growth Capability

Rockwell International
Rocketdyne Division

United States and Soviet Union STS Operations

STS-26 America's Pride: The Journey Continues

ENERGIA on Launch Pad with Buran (Blizzard) Side-Mounted

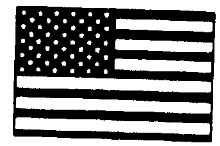
- Buran initial flight achieved 15 November 1988 as United States STS returns to operation (STS-26, Discovery) 29 September 1988
- United States STS operations continue:
  - STS-27, Atlantis, 2 December 1988
  - STS-29, Discovery, 13 March 1989
  - STS-30, Atlantis, 4 May 1989
  - STS-28, Columbia, 8 August 1989
  - STS-34, Atlantis, 18 October 1989
  - STS-33, Discovery, 22 November 1989
  - STS-32, Columbia, 9 January 1990
  - STS-36, Atlantis, 28 February 1990
  - STS-31, Discovery, 24 April 1990
- United States next flight:
  - STS-38, Atlantis, Summer 1990 (secret mission)
  - STS-35, Columbia, Summer 1990 (Astronomical observatory, UV & X-ray telescopes – 1 week)
- Soviet Union next flight:
  - Late 1991 – unmanned of several days duration, docking with MIR, equipment checkout & rescue simulation, automatic return

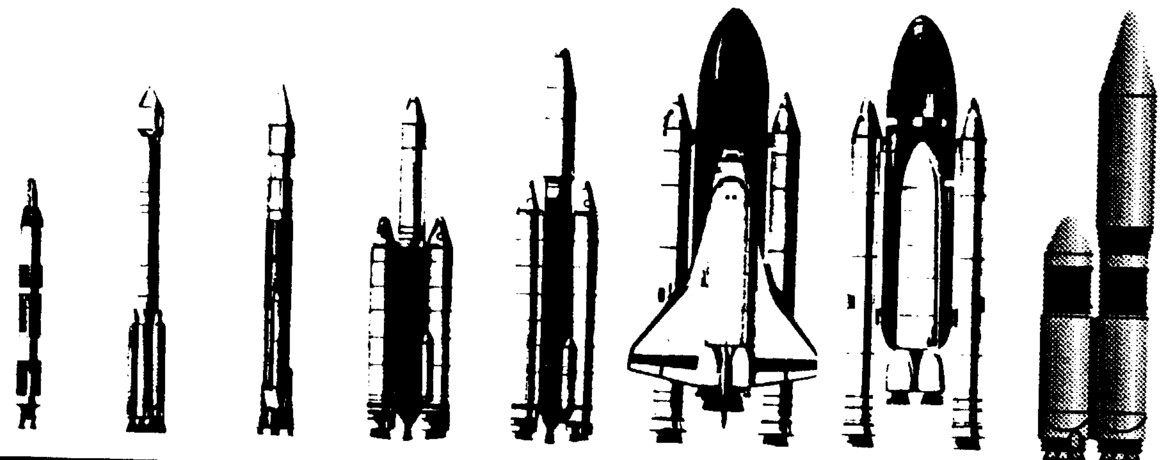
Rockwell International
Rocketdyne Division

LC88d-9-3336C
610

ORIGINAL PAGE IS
OF POOR QUALITY

U.S. Launch Vehicles

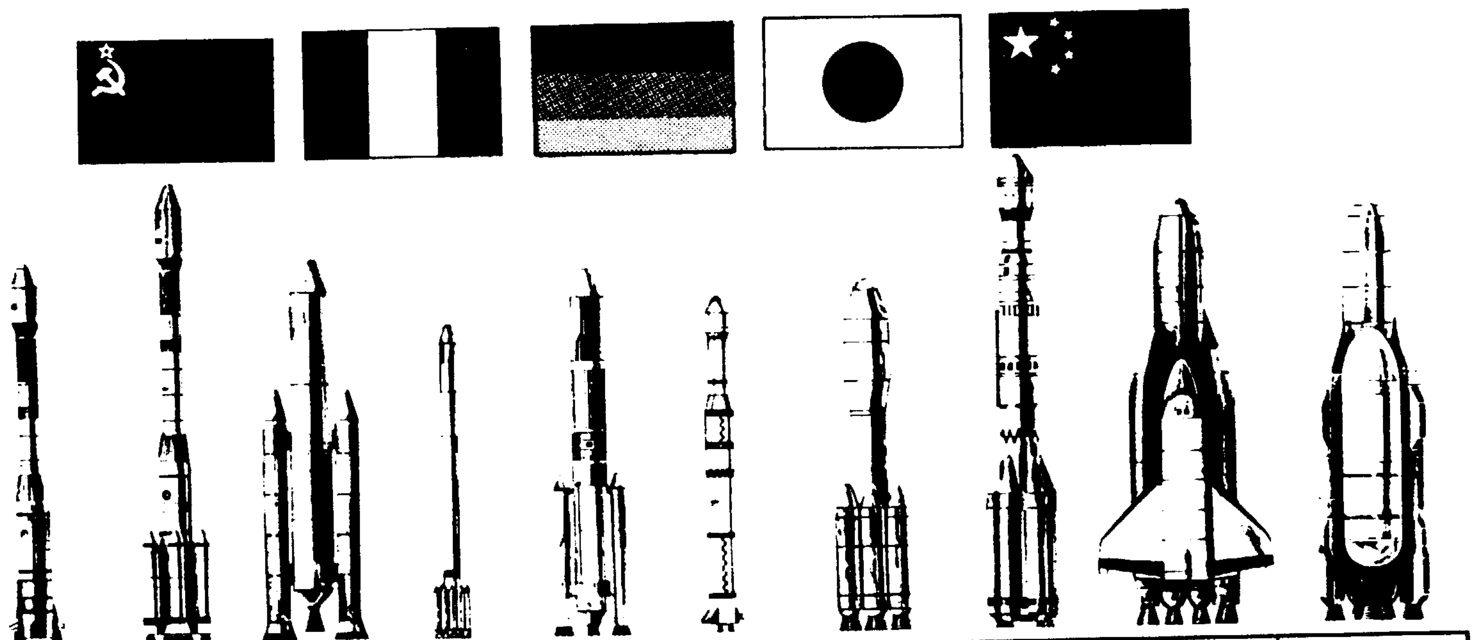




Class	Titan 2	Delta 2	Atlas Centaur	Titan 3	Titan 4	Shuttle	Shuttle C	ALS
LEO (lb)	5,500	11,100	12,300	33,000	42,000	55,000	100,000 -150,000	80,000-220,000
GEO-Transfer (lb)	-	3,190	5,200	8,600	12,500	-	-	-
GEO-Circular (lb)	-	1,350 (PAM-D)	2,500	4,200 (IUS)	10,000 (Centaur)	1,350 (PAM-D) 5,000 (IUS) 6,500 (TOS)	20,000 (Centaur)	-
Inventory	13 Being Refurbished*	20 Ordered	18 Ordered	Reservations for 19 Satellites	48 Ordered	-	-	-
Flight Schedule	First Flight Mid 1988	First Flight Late 1988	First Flight 1990	First Flight 1989	First Flight Late 1988	Return-To-Flight 1988	First Flight (4 years from go-ahead)	First Flight 2000

Rockwell International
Rocketdyne Division

International Launch Vehicles

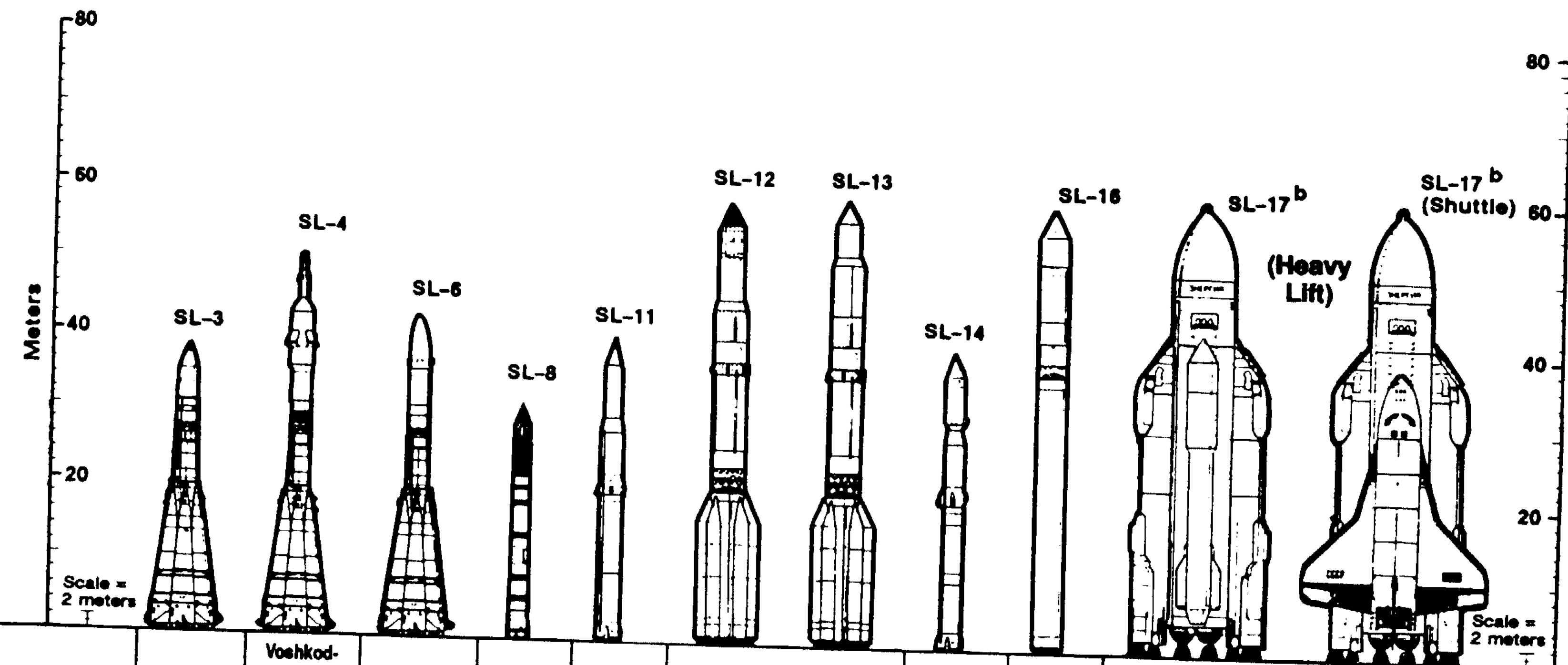


Class	Ariane 3 (Arianespace)*	Ariane 4 (Arianespace)*	Ariane 5 (France)	H-1 (Japan)	H-2 (Japan)	Long March-3 (PRC)	Long March-4 (PRC)	Proton (CCCP)	Energia with Orbiter (CCCP)	Energia HLLV (CCCP)
LEO (lb)	—	—	46,200 (Hermes Spaceplane)	—	—	—	20,000	44,000	66,000	220,000
GEO-Transfer (lb)	5,690	9,260	14,960	2,300	9,000	5,500	8,800	10,000	—	—
LEO-Circular (lb)	2,780	4,800**	7,750	1,210	4,000	2,500	4,000	4,800	—	—
Advertised Flight Rate	4/year	4/year	—	2/year	2-4/year	2-5/year	—	—	—	—
Flight History	17/21 (81%) (Ariane 1, 2 & 3)	First Flight Mid 1988	First Flight 1995	Initial Two Flights 1986/1987	First Flight 1992	Initial Two Flights 1987	First Flight 1991	122/132 (92.4%)	First Flight Nov 1988	One Test Flight May 1987

* European consortium dominated by France (60%) and West Germany (20%)
** Six version of Ariane 4 ranging from 2,300 to 4,800 lbs GEO-Circular

Rockwell International
Rocketdyne Division

USSR Launcher Family



-	Vostok	Voshkod-Soyuz	Molniya	Cosmos		Proton		Tsyklon	Zenit	ENERGIA	
Lift-Off Weight (kg)[a]	290,00	310,000	310,000	120,000	180,000	680,000	670,000	190,000	400,000	2,300,000	2,300,000
Lift-Off Thrust (kg)[a]	410,00	420,000	420,000	160,000	280,000	900,000	980,000	280,000	600,000	3,550,000	3,550,000
Payload to 180 km (kg)[a]	6,300	7,500	-	1,700	4,000	-	21,000	5,500	15,000+	105,000	30,000

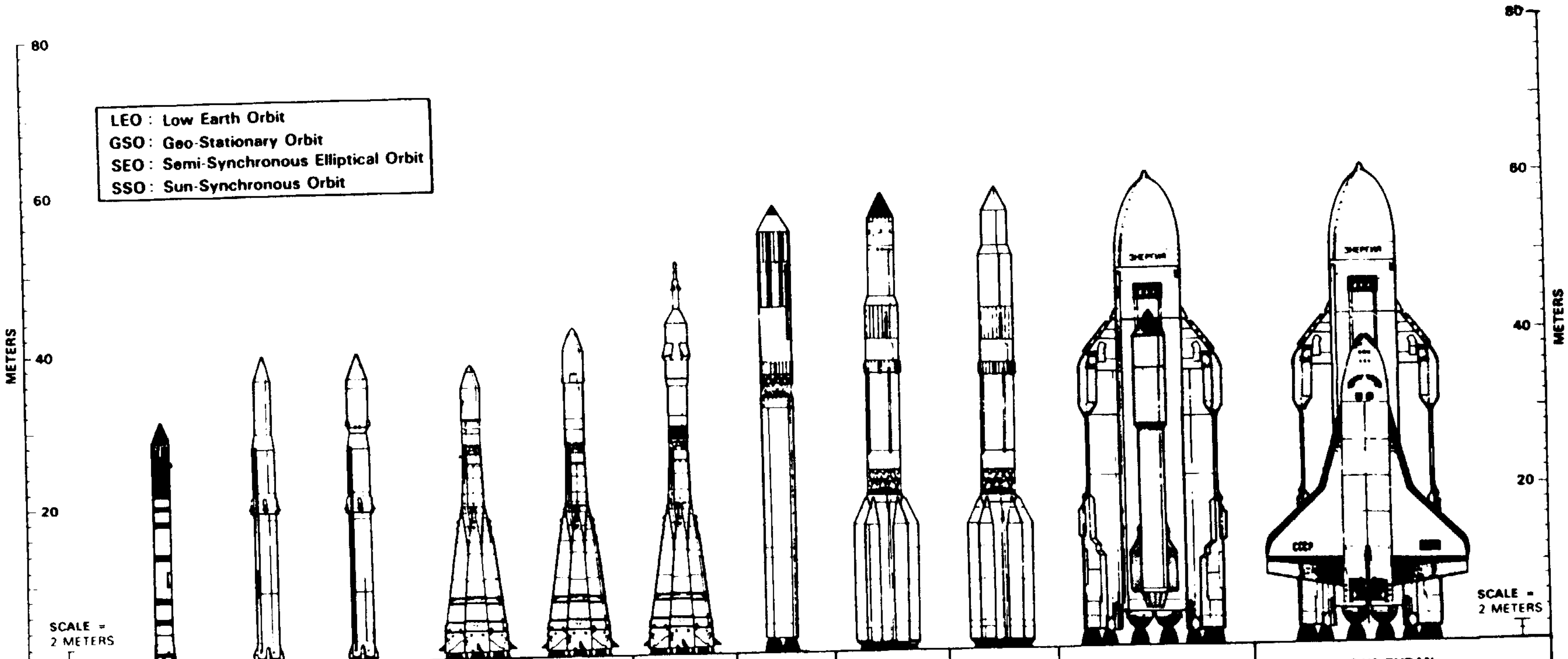
[a]Approximate
[b]In final stages of development

- With the successful launch of the Buran shuttle, the Soviet launch vehicle arsenal now includes 11 major variants capable of launching payloads from 1,700 to more than 100,000 kg

Rockwell International
Rocketdyne Division

LAUNCH VEHICLES

LEO : Low Earth Orbit
GSO : Geo-Stationary Orbit
SEO : Semi-Synchronous Elliptical Orbit
SSO : Sun-Synchronous Orbit



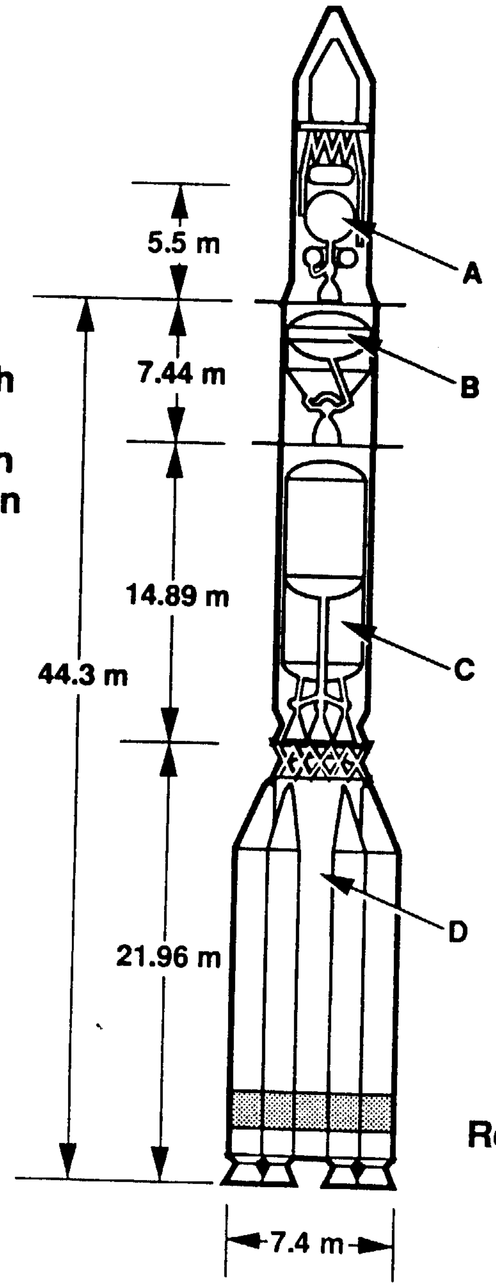
USSR NAME	KOSMOS	—	TSYKLON	VOSTOK	MOLNIYA	SOYUZ	ZENIT	PROTON	PROTON	ENERGIYA	ENERGIYA/BURAN
US DESIGNATOR	SL-8	SL-11	SL-14	SL-3	SL-6	SL-4	SL-16	SL-12	SL-13	SL-17	SL-17
AVERAGE ANNUAL LAUNCHES (1980's)	15	5	7	2	11	41	2[a]	9	1	1[b]	1[c]
OPERATIONAL PAYLOAD CAPACITY (KG)	1,350(LEO)	—	4,000(LEO)	4,730(LEO) 1,840(SSO)	1,800(SEO)	7,240(LEO)	13,740(LEO) 11,380(SSO)	5,700(Moon) 5,300(Venus) 4,600(Mars) 2,500(GSO)	20,600(LEO)	105,000(LEO) 32,000(Moon) 28,000(Mars/Venus) 19,000(GSO)	30,000(LEO)

[a]SINCE 1985 [b]SINCE 1987 [c]SINCE 1988

TELEDYNE BROWN ENGINEERING

Soviet Proton Space Launcher SL-12

- Payloads (t)
  - 20.0 - 200 km-Earth orbit
  - 5.7 - Lunar mission
  - 5.3 - Venus mission
  - 4.6 - Mars mission
  - 2.2 Geostationary mission



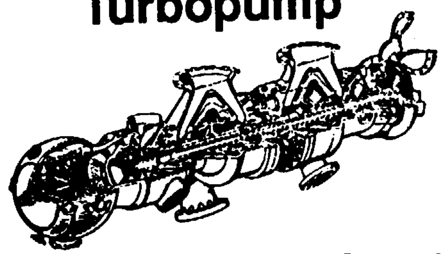
- Fourth Stage (A)
  - One engine (staged combustion) Thrust = 84.35 kN (18,963 lb)
  - LOX/kerosene
- Third Stage (B)
  - One engine same as the 2nd stage Thrust = 0.6 MN (134,885 lb)
  - Four chamber (open cycle) for thrust vector control with a thrust = 30 kN (6,744 lb)
- Second Stage (C)
  - Four engines (staged combustion) Thrust = 4 x 0.6 MN (539,542 lb)
  - N_2O_4 /UDMH
- First Stage (D)
  - Six RD-253 engines Thrust = 6 x 1.474 MN (1,988,210 lb)
  - N_2O_4 /UDMH

Ref: Aviation Week & Space Technology, October 13, 1986, page 19
Encyclopedia of Cosmonautics, page 307

Rockwell International
Rocketdyne Division

RD-253 Engine Schematic

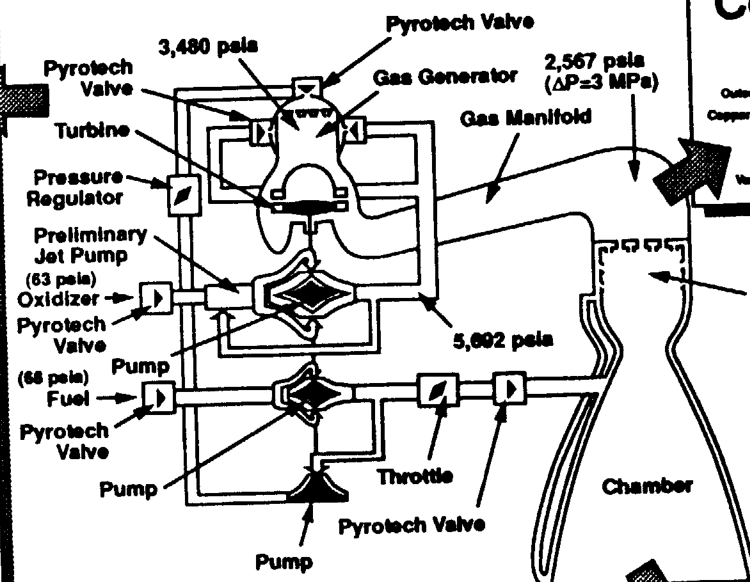
Turbopump



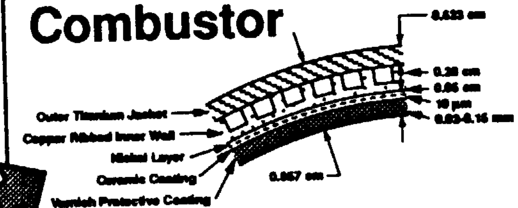
RD-253 Version 1 - Design Concept

1 - Pump (UDMH)
2 - Pump (N_2O_4)
3 - Preburner
4 - Mounting flange (aux. pump spin cartridge)
5 - Axial-flow turbine
6 - Spin turbine

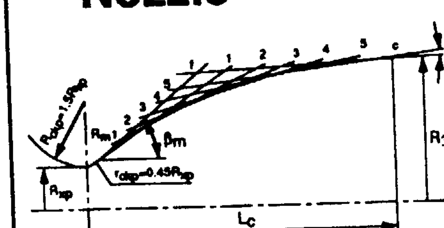
- Single shaft with three centrifugal impellers with double entry & axial-flow reaction turbine
- Maximum N_2O_4 pump discharge pressure, 5,692 psia
- Maximum rotational speed, rpm = 13,860
- Weight = 551 lb
- % of engine weight = 20
- Fuel, UDMH, pump is 2-stage
- Turbine output, 25,130 hp
- Pressure ratio = 1.356
- Turbine efficiency = 75% (est.)
- Inlet temperature = 1404 °R
- Inlet pressure = 3,480 psia
- Propellants N_2O_4/UDMH at mr = 41.5

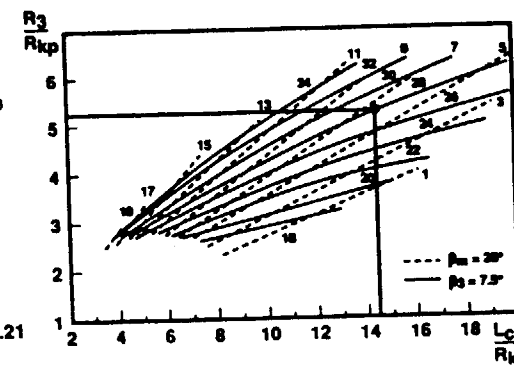


Combustor



Nozzle

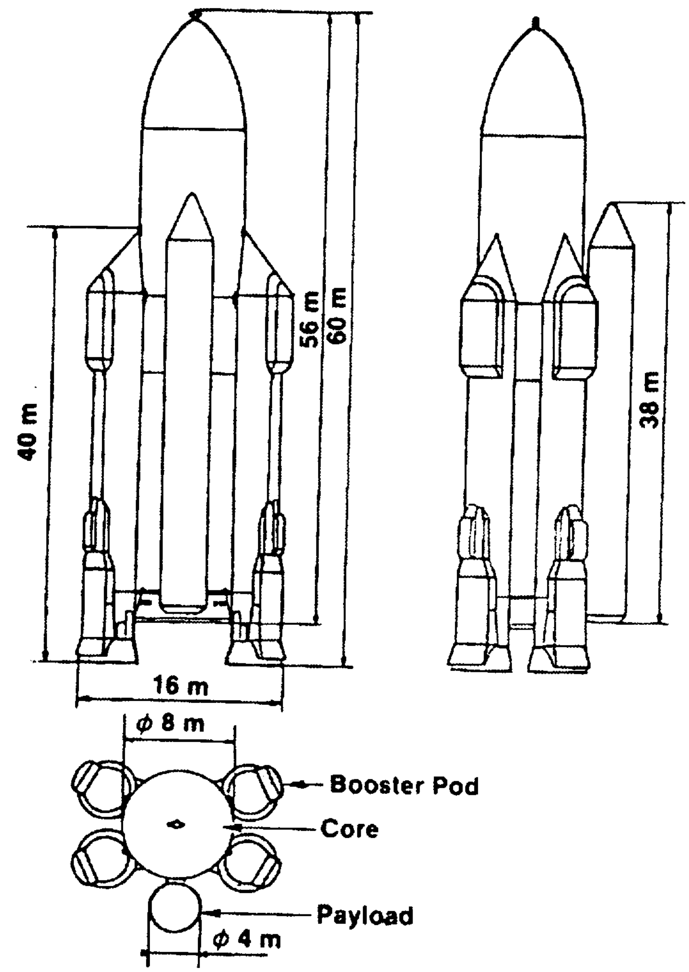




$$\frac{R_3}{R_{kp}} = \sqrt{\varepsilon} = 5.10 \quad \frac{L_c}{R_{kp}} = \frac{2\,(72.04)}{10.9046} = 13.21$$

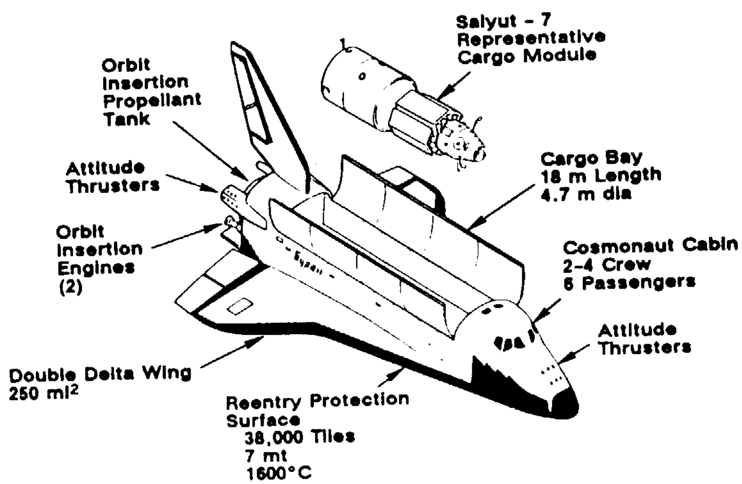
Rockwell International
Rocketdyne Division

ENERGIA Views



Rockwell International
Rocketdyne Division

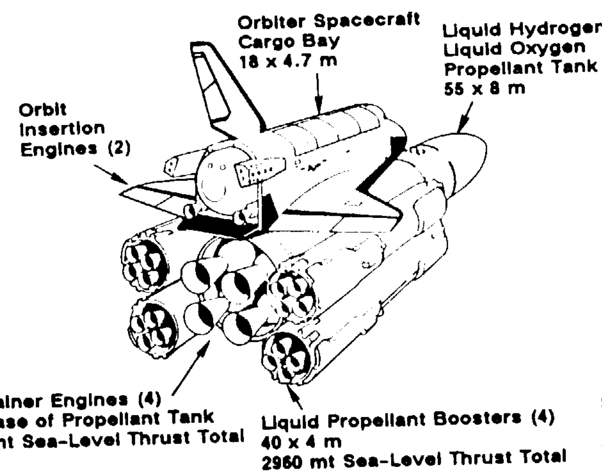
A Comparison of the U.S. and USSR Space Shuttles Reveals Them to be Functional Twins



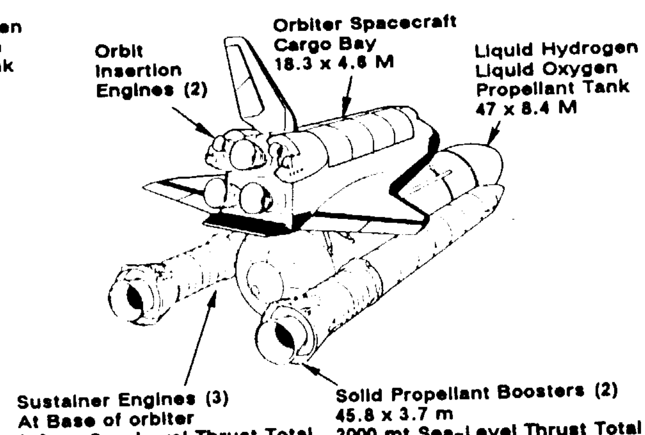
	Buran	US STS
Year of Maiden Flight	1988	1981
Orbiter Dimensions		
Length (m)	36.4	37.2
Height (m)	16.5	17.3
Body width (m)	5.6	5.5
Wing span (m)	24.0	23.8
Maximum Mass at Launch		
Orbiter (metric tons)	75	98
Payload (metric tons)	30	24
Total (metric tons)	105	122
Maximum Mass at Landing		
Orbiter (metric tons)	62	86
Payload (metric tons)	20	15
Total (metric tons)	82	100
Total System at Launch		
Length (m)	60	56
Mass (metric tons)	2,400	2,058
Number of main engines	8	5
Thrust (metric tons)	3,552	3,510

(Buran masses are design values; US STS masses are demonstrated)

Soviet Space Shuttle



U.S. Space Shuttle



Rockwell International
Rocketdyne Division

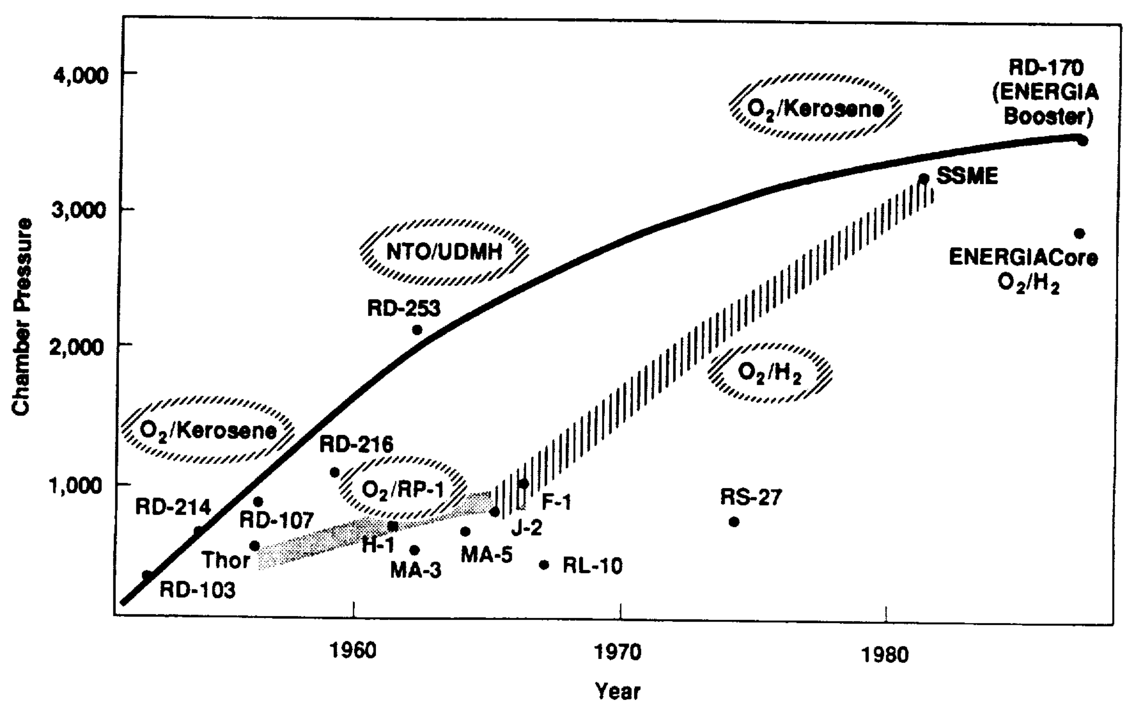
Courtesy: D. R. Woods

Glasnost Provides News of ENERGIA

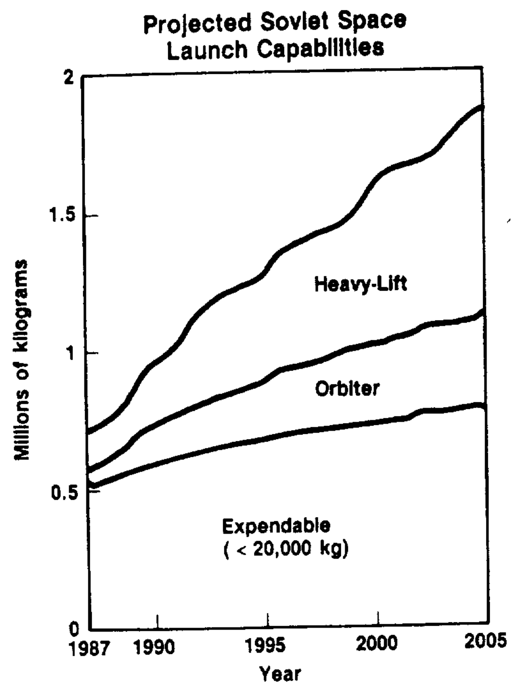
Significant news articles with photographs have been released concerning ENERGIA including substantial quotes from Alexander Duneyev (Glavcosmos head) & B. Gubanov (Chief Designer-ENERGIA). Additionally, a video was shown on Soviet television recently concerning the background of technology & initial launch of ENERGIA & of the promotion video of Cape York usage for the SL-16 (Zenith). Unclassified information was collected from the public domain & used to generate this briefing. The following sources were used:

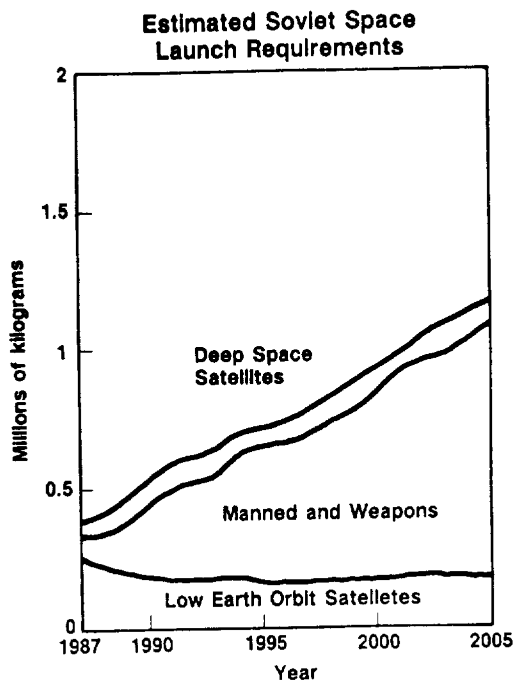
- Aviation Week & Space Technology
- Soviet Aerospace
- Compendium of Global Launch Vehicles (Rockwell STS Division)
- Data Base - International Space Launchers
- Flight International
- Defense Daily
- Janes Defense Weekly; Janes Intelligence Review
- Teledyne Brown Engineering - Soviet Year in Space (1986, 1987, 1988, 1989)
- Space Magazine
- The Development of Rocket Engineering & Cosmonautics in the USSR, V. Glushko, 1987
- Moscow Pravda articles
- Soviet video - "ENERGIA Is Off"
- Soviet video - "Soviet Zenith launcher (Cape York)"
- Paris Air Show display, 1989
- Soviet Military Power 1988, 1989
- Air & Cosmos
- Space markets
- 40th Congress of the IAF (ENERGIA; B. Gubanov)

Chamber Pressure Trends in Rocket Engines

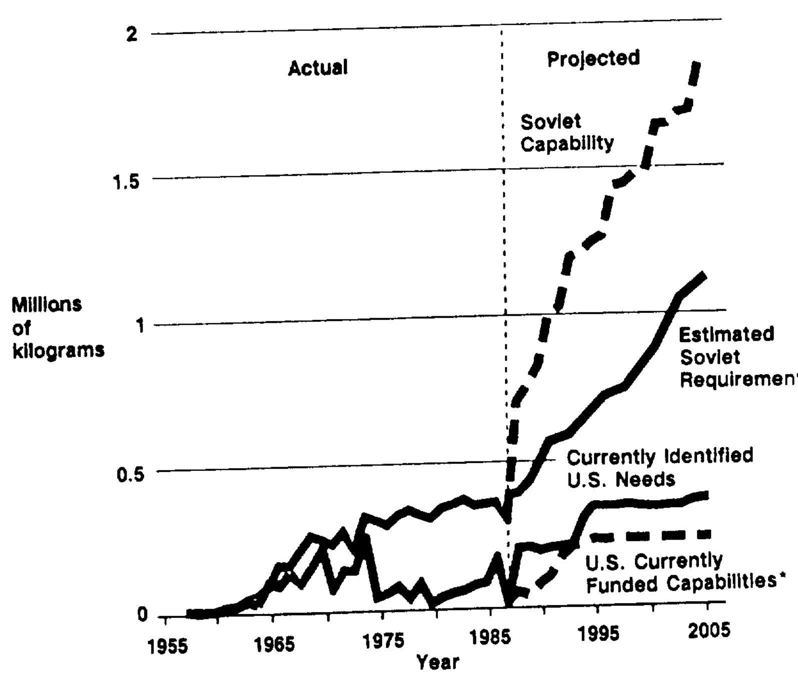


Projected Soviet Space Launch Capability Almost Double the Estimated Requirement by 2005





Comparison of United States and Soviet Weight to Orbit Profiles



*Does not include the proposed Advanced Launch System

Rockwell International

ENERGIA – A New Versatile Rocket Space Transportation System

(40th IAF Congress, October 1989, B.I. Gubanov, Glavcosmos, Moscow, USSR)

- Soviet Soyuz opened unmanned & manned space flight era
- Soviet Proton launcher enabled orbiting space stations, vehicles for lunar/planetary study, & means of earth exploration from space
- Soviet VRST system opens new phase of space commercialization
- ENERGIA side-mounted payload allowed independent development of launcher & orbiter
- First stage (booster) has four rocket modules (O_2/kerosene); modules are transported to cosmodrome from manufacturing plant by railway; each module is one rocket engine
- Second stage (core) has four rocket engines (O_2/H_2); core propulsion systems delivered to cosmodrome from manufacturing plant by airplane
- ENERGIA has payload versatility
  - Two booster modules, One core module } 65 tonne PL
  - Four booster modules, One core module } 100 tonne PL
  - Eight mod booster modules, One core module } 200 tonne PL
- ENERGIA features reliability & vitality (life)
  - Key system redundancy exists
  - Turbogenerator power supplies to core (quadrupled)
  - Booster stage batteries (doubled)

ENERGIA – A New Versatile Rocket Space Transportation System

(40th IAF Congress, October 1989, B.I. Gubanov, Glavcosmos, Moscow, USSR)

- ENERGIA development united >1,200 design offices, institutes, plants, assembly organizations, & academies
- 360 test stands/experimental facilities used including
  - 100 aerodynamic models
  - Booster & core engine test stands
  - Module hot fire test in-vehicle capability
  - 10:1 scale-down model of ENERGIA-Buran for launch load study
- 7,000 complex tests & tens of thousands of supporting tests conducted
- More than 100 O_2/H_2 engines manufactured
  - More than 600 engine tests in development (120,000 test-s)
  - Demonstration of 6-7 flight lives
- About 200 O_2/kerosene engines manufactured
  - More than 600 engine tests in development
  - Demonstration of 6-10 flight lives
- Supporting pnemo-hydraulic plumbing included 30,000 tests
- Launcher control system 65,000 tests
- Eight tests of full-scale booster modules & two tests of core modules successful
- Eight full-scale VRST systems produced (five ENERGIA & three ENERGIA-Buran complexes)

ENERGIA – A New Versatile Rocket Space Transportation System

(40th IAF Congress, October 1989, B.I. Gubanov, Glavcosmos, Moscow, USSR)

- ENERGIA development included new high strength steels, aluminum, & titanium alloys (representing 75% of dry weight)
- The ENERGIA is a heavy lift launcher that will allow delivery of Martian soil to earth & to subsequently perform manned Mars expeditions
- ENERGIA future projections
  - Growth by O_2/H_2 booster stage development
    - For 18 tonne GEO
    - For 32 tonne translunar
    - For 28 tonne Mars
    - A new cargo propulsion system (100 kN thrust, 490 s specific impulse for 5.5 dia stage)
  - Small transport module development (based on existing launcher) for space station placement to 1,000 km
    - An existing cargo propulsion system (O_2/kerosene; possibly Proton Stage IV engine; 85 kN thrust, 350 s specific impulse)
  - Special cargo module development (5.5 in. x 37 in.)
    - New side-mounted universal cargo container
  - General capabilities improvement; economics; reusability aspects
    - Possible new booster propulsion

Soviet SL-17 (ENERGIA) Booster Propulsion

Component Orientation

- The centrally located TPA is a single shaft assembly with high pressure fuel pump on the bottom, high pressure oxygen pump in the middle & turbine on top

- 1989 Paris Air Show display photographs indicate low pressure kerosene inlet ("angle"), low pressure oxygen inlet ("vertical"), preburners ("horizontal"), & four regeneratively cooled (fuel) TCAs.

- Each TCA is two-plane hinged for booster control

Soviet ENERGIA Booster Propulsion Display
Paris Air Show - 1989
RD-170 Placard

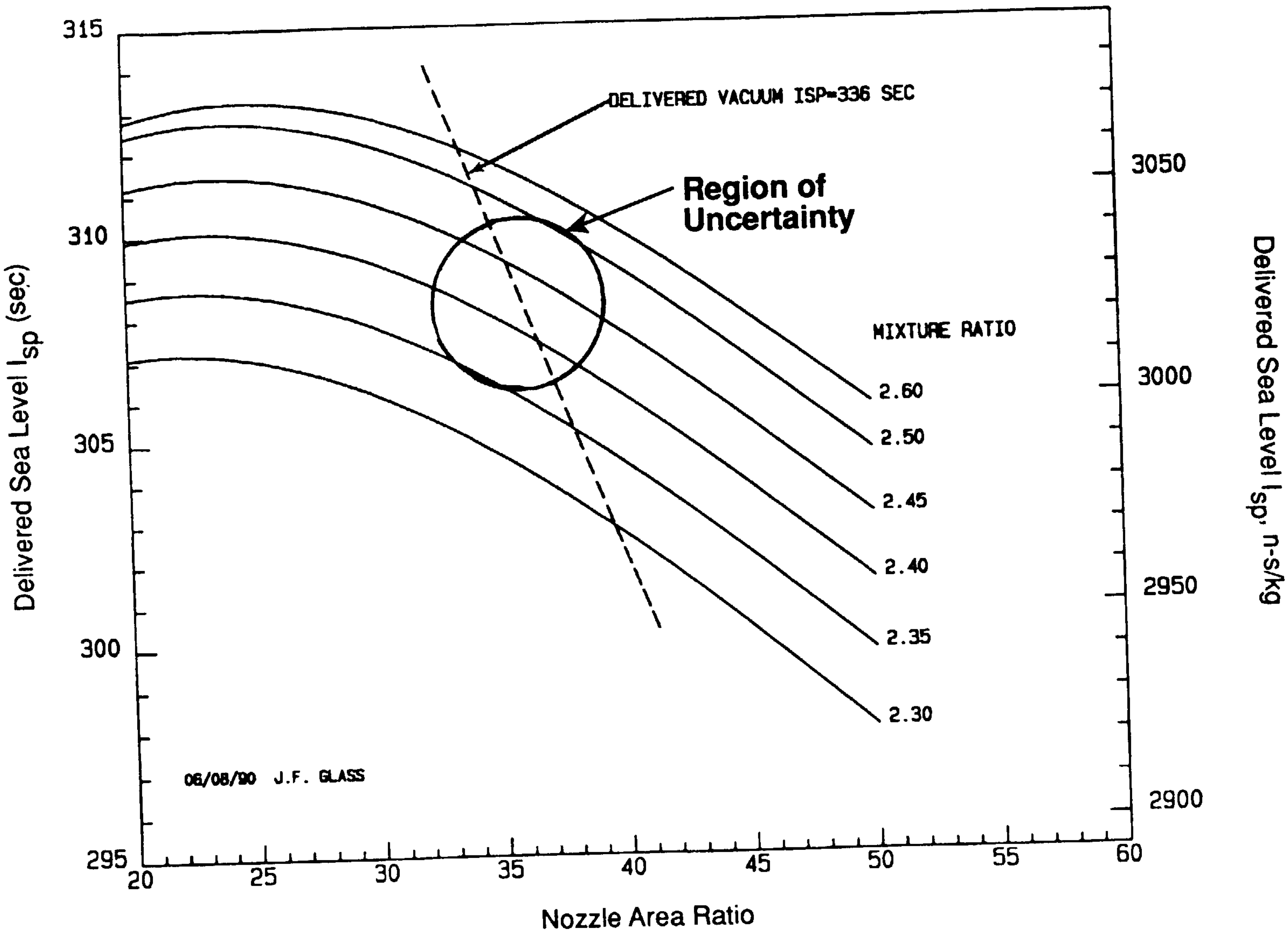
• Le propulseur est installe au premier etage de la fusee "ENERGUYA"	The rocket is installed in the first stage of the "ENERGIA"
• Poussee au sol - 740 ts (metric tons)	Thrust in atmosphere - 1,631,404 lb
• Poussee dans le vide - 806 ts (metric tons)	Thrust in space - 1,776,908 lb
• Impulsion specifique au sol - 308 s	Specific impulse in atmosphere - 308 s
• Impulsion specifique dans le vide - 336 s	Specific impulse in space - 336 s
• Pression dans la chambre de combustion - 250 kgs/cm2	Combustion chamber pressure (3,556 psi)
• Comburant: Oxygene	Oxidizer: Oxygen
• Propergol: Kerozene	Fuel: Kerosene

Soviet SL-17 (ENERGIA) Booster Propulsion

- Glushko Design Bureau has developed world's highest thrust & specific impulse 02/Kerosene engine
  - FSL 1,631,420 lb
  - FV 1,776,928 lb
  - ISSL 308 s
  - ISV 336 s
  - Pc 3,556 psi
  - MR 2.58
- This engine (RD-170) is recognized as a propulsion module & consists of 1 turbopump assembly driven by 2 preburners which feed 4 thrust chamber assemblies
  - Staged combustion power cycle
  - Single shaft TPA centrally located in booster pod
  - System includes low pressure pumps
- The RD-170 engine has flown 29 times
  - Twenty-one as SL-16 (ZENITH) booster since 1985 (21 flights, 1 pod/launcher)
  - Eight as SL-17 (ENERGIA) booster since 1987 (2 flights, 4 pods/launcher

Rockwell International

ENERGIA Booster Propulsion Performance Profile
(O_2/Kerosene Specific Impulse As A Function of Area Ratio & Mixture Ratio)



Rockwell International
Rocketdyne Division

Design Comments on RD-170 Photographs

(R. Saxelby, D. Southwick)

- Selected notes as of 25 July 1989
  - Fuel cooled nozzle & MCC
  - Fuel inlet is the one with flat cover. *BW-16, *BW-13
  - It is possible that only the upper half of nozzle is cooled (one pass cooling) *BW-10; others are shown on schematic
  - All of the chamber coolant goes directly to the injector/MCC. None (or very little) leaves the cooling circuit to go to the preburner *BW-12
  - Low pressure fuel boost pump. The pump is liquid driven *BW-16, -17. This is based on the fact that the turbine manifold is small & there isn't a turbine gas outlet
  - Low pressure liquid oxygen boost pump. Manifold *BW-3 shows the manifold feeding a turbine. The mirror view *BW-11, shows one of the feed lines that supply the manifold. A liquid oxygen driver is suggested since there isn't a turbine gas outlet
  - Single turbine/single shaft. No visual evidence of gearbox and/or more than one turbine (turbine could be multiple stages)

*BW = from B. Waldman photographs

Design Comments on RD-170 Photographs

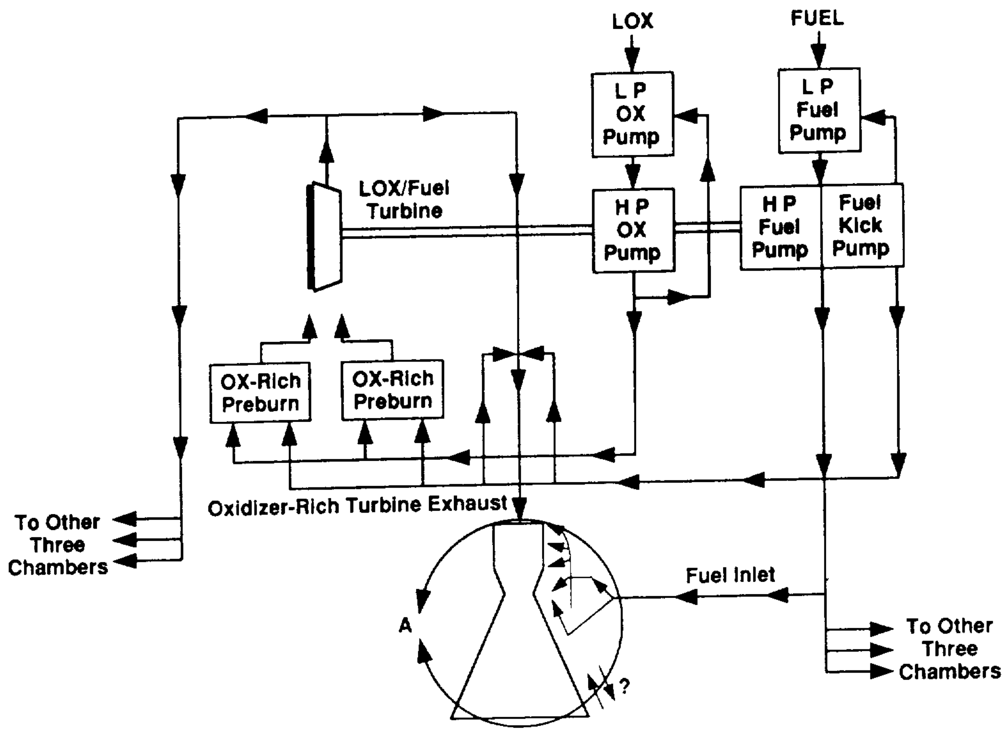
(R. Saxelby, D. Southwick)

- Selected notes as of 25 July 1989 (continued)
  - High pressure fuel turbopump is located at the bottom of the central unit *BW-16. HP fuel pump inlet is indicated in *BW-12. Main HP outlet goes to top of engines & splits into four pipes - each of which supplies a thrust chamber with coolant. Two smaller tubes leave HP fuel pump *BW-8. There might even be a high pressure fuel kick pump at the very bottom where the two just mentioned smaller tubes leave. Although it cannot be positively shown, it is believed that one line drives LP boost pump & one line goes to the preburners
  - High pressure OX pump is near middle of central unit *BW-2, -3, -19, *BW-15. The outlet of the pump goes to the two preburners *BW-8, -18
  - Turbine is on top of central unit. The turbine exhaust goes directly into the top of each thrust chamber. The inlet to the turbine comes from the straight section of the preburner *BW-15, -18, *BW-6, -4
  - Oxidizer rich preburner. All (or very much) of OX goes into preburner *BW-8
  - LOX pump seal possibly drains back into HP pump inlet. *BW-6, *BW-15

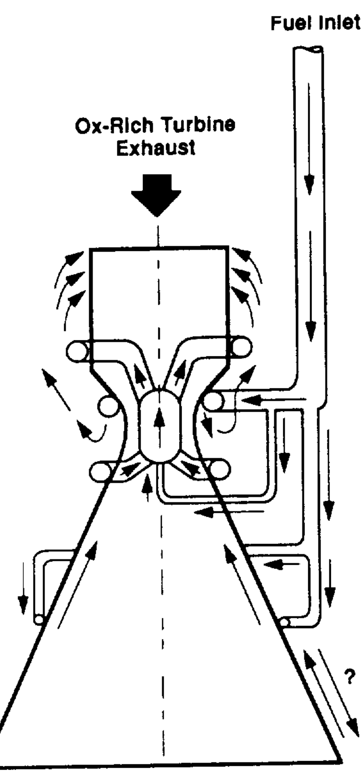
Rockwell International

*BW = from B. Waldman photographs

Soviet RD-170 Propulsion System Schematic Diagram
(Based on 1989 Paris Air Show Display Photos)



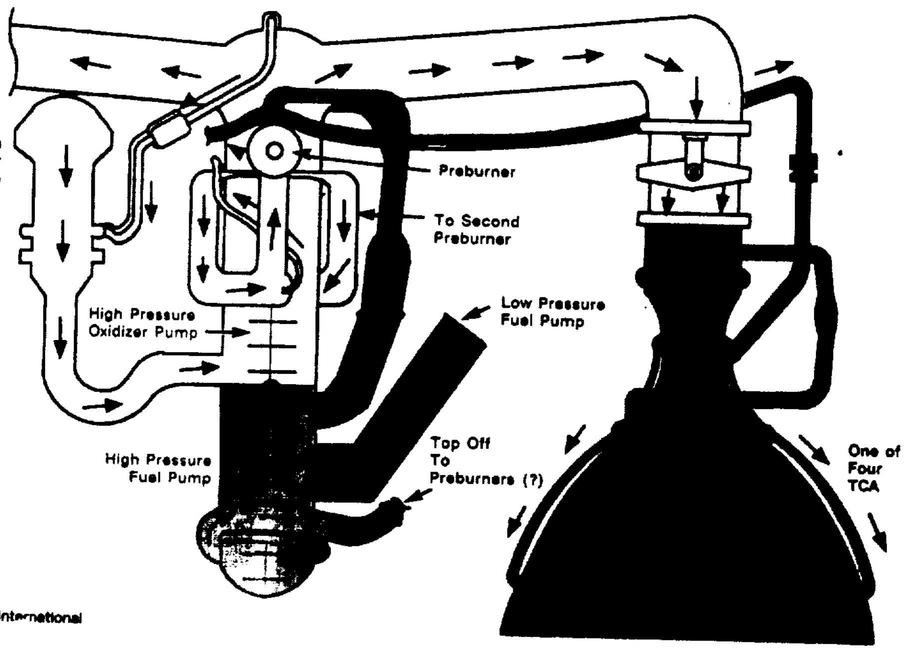
Soviet RD-170 Propulsion System Schematic Diagram
(Based on 1989 Paris Air Show Display Photos)



Rockwell International

Soviet RD-170 Propulsion System Schematic Diagram

(Preliminary Data: WPAFB-FTD 25 July 89)



Rockwell International

ORIGINAL PAGE IS OF POOR QUALITY

ENERGIA Booster Propulsion Characteristics Summary

Parameters	Metric Units		English Units
	kg/cm²	N/cm²	
Sea-level thrust (ea TC)	185 t		407,829 lbf
Vacuum thrust (ea TC)	201.5 t		444,223 lbf
Sea-level thrust (ea pod)	740 t		1,631,316 lbf
Vacuum thrust (ea pod)	806 t		1,776,892 lbf
Total booster thrust (sl)	2,960 t		6,525,264 lbf
Total booster thrust (vac)	3,224 t		7,107,568 lbf
Sea-level Isp	3024.9 n-s/kg		308.45 s
Vacuum Isp	3295 N-s/kg		336 s
Isp efficiency	.9439		
Chamber pressure Inj	250	2451.7	3556 lb/in.²
Chamber pressure Noz	233.68	2382.8	3456 lb/in.²
Area ratio	36		
Throat area	443.81 cm²		68.79 in.²
Delivered c*	1763.3 m/s		5,785 ft/s
Minimum gimbal angle	None (does not gimbal)		
Engine length	2.524 m		99.372 in.
Engine exit dia (ea)	142.63 cm		56.152 in.
Mixture ratio (o/f)	2.43 (from tanked masses, video, & performance)		
Flow rate, fuel (ea pod)	696.35 kg/s		1541.8 lb/s
Flow rate, oxidizer (ea pod)	1699.41 kg/s		3746.6 lb/s
Horsepower (4 chambers)	186,425 kW		250,000 hp

Booster Pod Propulsion
- One RD-170 engine per booster pod
- Staged-combustion power cycle
- Four thrust chambers fed by one turbopump set

ENERGIA Booster Engine Power Balance Analysis by Rocketdyne

- Baseline data
  - O_2/kerosene propellants
  - MR = 2.47 P_c = 3,556 psi
  - F_{sl} = 408 klb/chamber
  - I_{sl} = 308 s (ϵ = 40)
  - From Soviet text translations (Ovsyannikov & Borovskiy)
    - Staged combustion cycle favored for high P_c
    - Oxidizer-rich preburners favored (if fuel is not H_2)
    - Turbine pressure ratio = 1.3 – 1.8 for staged combustion
    - Maximum turbine inlet temperatures = 2160°R for fuel rich; 1440°R for oxidizer rich
- RD–170 simulation
  - Advanced heat transfer
  - Fuel-rich & oxidizer-rich preburners can meet 3,600 psia P_c
    - Within temperature limits
    - Requires kick pump stages and/or boost pumps
  - Mixed preburners can exceed 3,600 psia P_c
    - Within temperature limits
    - With or without boost pumps
  - Turbine pressure ratio ~2.0
  - Pump ΔPs ~12,000 psi → 9000 psi
  - $I_{sp_{vac}}$ = 339 with η_{c^*} = 0.96
  - It is noted fuel-rich preburners would tend to plug main injector (oxidizer-rich preburners would not)

RD–170 Turbopump Configurations Evaluated to Yield 3,600 psia P_c

Case	Pre-burner	Shafts	Main Pump Stages		Kick Pump Stages		Boost Pumps		Required Turbine Inlet Temperature (°R)
			Fuel	Oxidizer	Fuel	Oxidizer	Fuel	Oxidizer	
1	FR	1	2	2	0	0	0	0	2390
2	FR	1	2	1	1	1	0	0	2130 ✓
3	OR	1	3	2	0	0	0	0	1760
4	OR	1	1	2	1	0	0	0	1680
5	OR	1	1	2	2	0	0	0	1540
6	OR	1	1	2	2	0	1	1	1440 ✓
7	Mixed	2	2	2	0	0	0	0	1840/1440 (F/O)
8	Mixed	2	2	2	0	0	1	1	1750/1250 (F/O)

✓ Acceptable

Rockwell International

Preliminary Engine Balance Data for RD-170 Booster Engine

(Selected Turbomachinery Parameters)

TYPE	(NONE)	OXI-DIZER PRESSURE	FUEL REACTION	HYDROGEN PRESSURE
# OF STAGES	(NONE)	2.00	2.00	.00
HORSEPOWER	(HP)	.	294,400	.00
FLOWRATE	(LB/SEC)	.00C	3817	.00000
EFFICIENCY	(NONE)	.00000	.83837	.00000
PRESSURE RATIO	(NONE)	2.227	2.227	.000
ADMISSION	(FRACTION)	1.000	1.000	.000
VELOCITY RATIO	(NONE)	.000	.501	.000
PITCH DIAMETER	(IN)	.000	19.54	.000
1ST STG BLADE HEIGHT	(IN)	.000	2.672	.000
2ND STG BLADE HEIGHT	(IN)	.000	4.316	.000
PITCHLINE VELOCITY	(FT/SEC)	1061.85	904.45	.00
INLET HUB/TIP RATIO	(NONE)	.000	.759	.000
EXIT HUB/TIP RATIO	(NONE)	.000	.638	.000
TIP SPEED	(FT/SEC)	.00	1104.17	.00
BEARING DN*E-6	(MM*RPM)	.000	1.910	.000
ANNULUS AREA*N**2*E-10	((IN*RPM)**2)	.000	2.976	.000
INLET PRESSURE	(PSIA)	9626.18	9626.18	.00
OUTLET PRESSURE	(PSIA)	4322.17	4322.17	171.69
INLET TEMPERATURE	(DEG R)	.00	1440.00	1440.00
OUTLET TEMPERATURE	(DEG R)	.00	1218.59	.00
1ST BLADE TEMPERATURE	(DEG R)	.00	1380.22	.00
2ND BLADE TEMPERATURE	(DEG R)	.00	1269.51	.00
MOMENT OF INERTIA	(FT-LB-SEC**2)	.075		.000
TIME CONSTANT	(SEC)	.000		.000

Rockwell International
Rocketdyne Division

Preliminary Engine Balance Data for RD-170 Booster Engine
(Selected Turbomachinery Parameters)

PUMP DESCRIPTION	(UNITS)	MAIN PUMP OXIDIZER	MAIN PUMP FUEL	KICK PUMP OXIDIZER	KICK PUMP FUEL
# OF STAGES	(NONE)	2.00	1.00	.00	2.00
HORSEPOWER	(HP)	205,500	49,770		39,140
ROTATING SPEED	(RPM)	10,600	10,600		10,600
EFFICIENCY	(NONE)	.80724	.76478	.00000	.73933
INLET PRESSURE	(PSIA)	65.00	45.00	.00	4824.52
OUTLET PRESSURE	(PSIA)	12091.69	4824.52	.00	12091.69
FLOWRATE	(LB/SEC)	3752	1519		760
	(GPM)	23,650	13,650		6,827
INDUCER					
TIP DIAMETER	(IN)	13.36	11.12		
TIP SPEED	(FT/SEC)	617.90	514.55		.00
INLET FLOW VELOCITY	(FT/SEC)	61.75	51.42		40.81
FLOW COEFFICIENT	(NONE)	.100	.100	.000	.100
IMPELLER					
TIP DIAMETER	(IN)	19.34	19.74		17.00
TIP SPEED	(FT/SEC)	895.45	914.01	.00	786.75
TIP WIDTH	(IN)	1.46	.972		.704
HEAD COEFFICIENT	(NONE)	.488	.531	.000	.545
BLADE ANGLE	(DEG)	25.000	25.000	25.000	25.000
HEAD RISE (OVERALL)	(FT)	24313.39	13781.57	.00	20954.58
STAGE SPECIFIC SPEED	(RPM*GPM**.5/FT**.75)	1407.70	973.66	.00	845.62
HEAD RISE (ISENTROPIC)	(FT)	24313.39	13781.57	.00	20954.58
EFFICIENCY (ISENTROPIC)	(NONE)	.80724	.76478	.00000	.73933
HUB/TIP RATIO	(NONE)			.000	.301

Rockwell International
Rocketdyne Division

Rocketdyne Power Balance Analysis Conclusions for RD-170 Engine

- ENERGIA booster engine must be staged combustion to obtain 308 sec I_{sp} at 3,556 psi P_c
- Oxidizer-rich preburner avoids injector plugging
- Fuel kick pump helps maximize energy utilization
- Boost pumps help obtain high pump η at low tank pressures
- Power balance analysis doesn't answer 1 vs 4 tip set/pod question; but Paris Air Show 1989 display does!

Heat Transfer Considerations - RD-170 Booster Engine

- **Severe engine operating conditions**
- **Regenerative cooled construction**
- **Candidate coolants**
  - LO_2
  - LH_2 (from core engine)
  - Kerosene
- **Methods for reducing heat flux & pressure drop losses**
  - Ceramic coatings
  - Fuel-rich outer zone (carbon layer)
  - Silicon oil additive

Rockwell International

RD–170 Propulsion System Cooling Feasibility Verified

- P_c = 3,556 psia
- O_2/kerosene (MR = 2.47)
- Nozzle 40:1

Heat transfer analysis

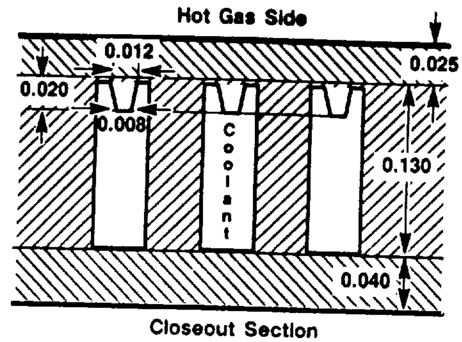
- Advanced heat transfer analysis applied
- Data base from NAS8–3657
- Modeled small throat radius ratio SSME geometry
- NARloy-Z chamber with milled, finned channels & electroformed closeout
- Peak q/A at 70 Btu/in²-s (ϵ_c = 2.66, ϵ_e = 5)
- 430 channel design (0.035 in. width x 0.130 in. depth)

Kerosene as regenerative coolant

- Coking limit 1200°R (high fuel velocity < 500 ft/s)
- Hot gas wall limit 1600°R (Cu-alloy)
- Bulk coolant limit 900°R
- Fuel pump discharge pressure < 12,000 psi

Coatings, fuel-rich bias injection, & silicon oil additive also considered

Channel Geometry



RD-170 Cooling Feasibility Throat Parameters Comparison
(Finned Channel Construction)

- Kerosene as coolant

Case	Q/A* (B/in.2-s)	%hg* (B/in.2-s-F)	Twg* (°F)	Twc* (°F)	$\dot{w}_c$ (#/s) 65.4%	ΔP (#/in.2)	ΔTc (°F)	Vc* (#/s)
1	75.6	100	1205	798	250	2,320	219	409
2	69.1	90	1126	755	250	2,319	202	408
3	62.4	80	1035	711	250	2,318	184	408
4	55.5	70	960	664	250	2,320	166	407

- Kerosene as coolant plus coating

Case	Coating (in.)	%hg*	hg*
0	0	100	0.151
1	0.001	87.9	0.01327
2	0.002	78.9	0.01191
3	0.003	71.5	0.0108
4	0.004	65.4	0.00988

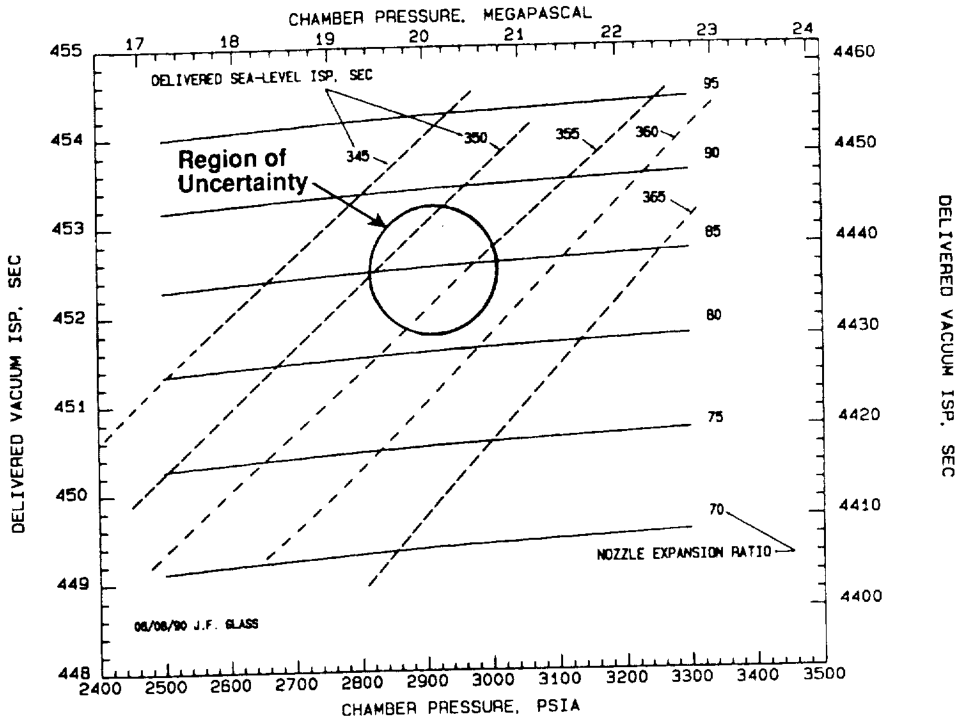
- Kerosene as coolant plus film cooling

Case	%$\dot{w}_f$	%$\dot{w}_g$	%hg*
1	0	0	100
2	5	1.49	85
3	10	2.98	70
4	15	4.48	60
5	20	5.97	50
6	25	7.46	40

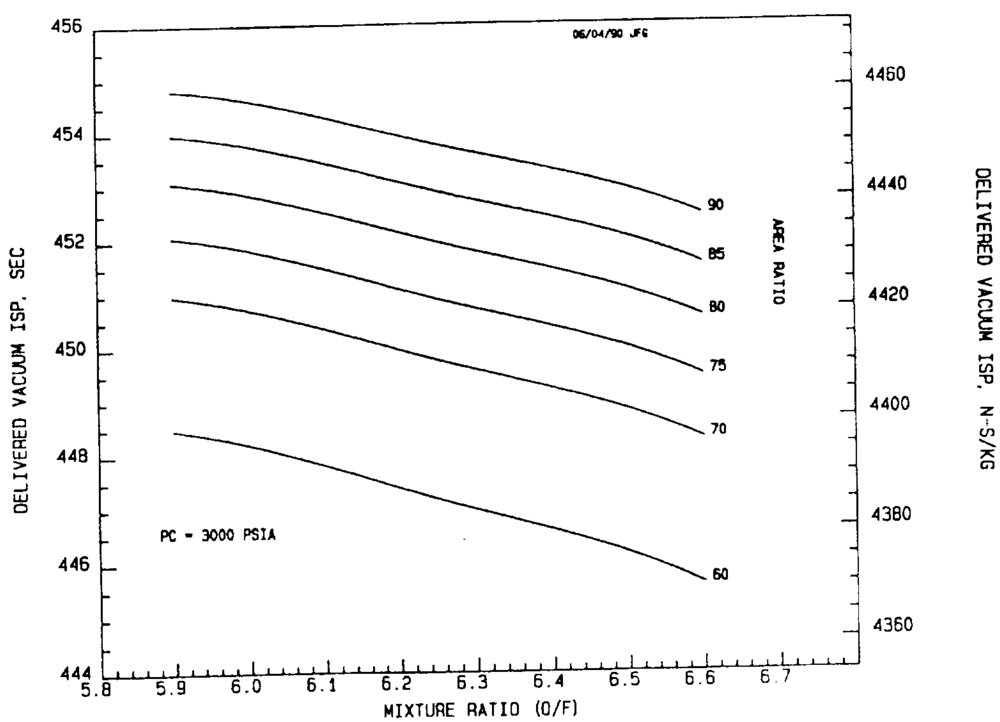
*K = 5 Btu/hrft°F
Nicraly-Zirconia Mix

Rockwell International

ENERGIA Core Propulsion Performance Profile
(O_2/H_2 Specific Impulse As A Function of Chamber Pressure & Area Ratio)



ENERGIA Core Propulsion Performance
I_{svac} As A Function of Mixture Ratio For Several Area Ratio Values



Rockwell International

Soviet ENERGIA O2/H2 Core Engine Design Comments
(Based on WPAFB-FTD Photographs)

- Most likely power cycle is staged combustion (performance basis)
- Single preburner or top of main combustor drives both pumps
- Nozzle has full external structural jacket with hatbands on lower 2/3 only. The half-round, closer spaced hatbands are insulated; less costly, but less efficient than the square hatbands. (Spot welds indicate thick jacket)
- Nozzle cooling via single up-pass (two inlets at nozzle exit) followed by dump cooling at forward end with low-pressure coolant (supports high operating mixture ratio & double wall design). Nozzle inside surface is smooth (nontubular construction).
- Heat shield support structure with drain/feedline penetrations is continuous ring with webbed load ribs

Soviet ENERGIA O2/H2 Core Engine Design Comments
(Based on WPAFB-FTD Photographs)

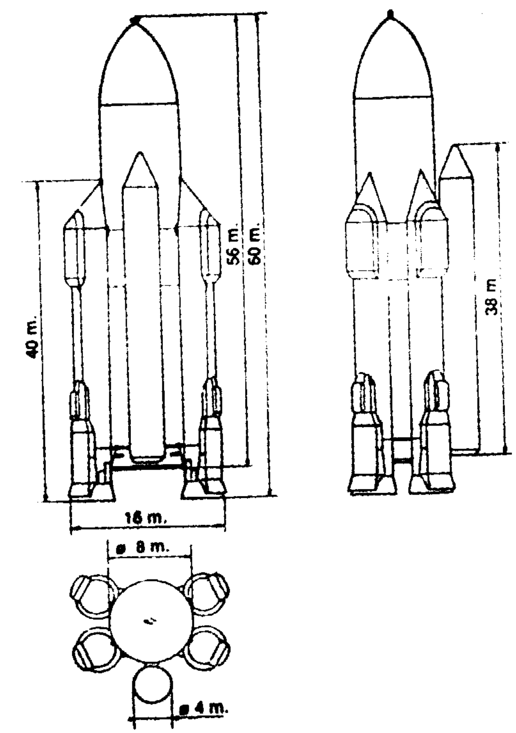
- Drain lines run parallel for nozzle coolant feedlines (angled to accommodate thermal movement). Two lines are insulated (possibly hydraulic 0:1). Numerous lines indicates multiple turbopumps involved in power pack
- Considerable use of insulation on components/ducting. Brown (polyurethane) & white (sealant) are wrapped/sprayed on
- Small white canister shapes may be SPGG units or electromechanical actuator or motors for preburner or coolant valves
- Shaped cylinder could be for POGO suppressor, or pressure bottle for inert gas for turbopump

Rockwell International

ENERGIA Vehicle Characteristics Summary

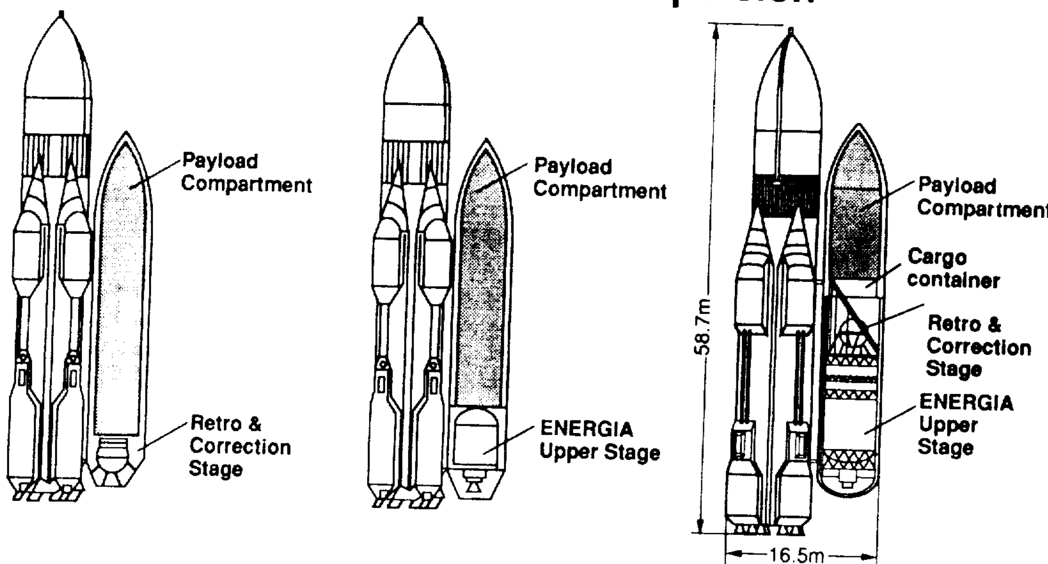
Vehicle Characteristics

Parameters	Metric Units	English Units
Min. liftoff accel	1.48 g	
Max. liftoff accel	1.77 g	
Max. liftoff mass	2,400 t	5,291,040 lb
Max. liftoff thrust	3,552 t	7,830,739 lbf
Duration, core section	455.0 s	7.583 min
Duration, booster section	137.4 s	2.289 min
Total vehicle ΔV	8814.3 m/s	28,918 ft/s
ΔV during booster burn	3514 m/s	11,529 ft/s
ΔV during core-only	5300.4 m/s	17,389 ft/s
Average booster I_{sp}	3185.2 N-s/kg	324.8 s
Average core I_{sp}	3998.2 N-s/kg	407.7 s
Core fuel load } MR 6	114.29 t	251,954 lb
Core oxidizer load } MR 6	685.71 t	1,511,724 lb
Booster fuel load } MR = 2.47	379.83 t	837,367 lb
Booster oxidizer load } MR = 2.47	938.17 t	2,068,296 lb
Total fuel load	494.12 t	1,089,337 lb
Total oxidizer load	1623.88 t	3,580,006 lb
Vehicle length	60 m	196.85 ft
Vehicle diameter	16 m	52.49 ft
Core diameter	8 m	26.25 ft
Booster diameter	4 m	13.12 ft
Booster length	40 m	131.23 ft
Payload diameter	4 m	13.12 ft
Payload length	38 m	124.67 ft
Payload capability (min)		
LEO	100 t	220,000 lb
GEO	18 t	39,683 lb
Lunar trajectory	32 t	70,547 lb
Martian trajectory	28 t	61,729 lb



Rockwell International
Rocketdyne Division

ENERGIA Mission Growth Capability Via Cargo Container Propulsion



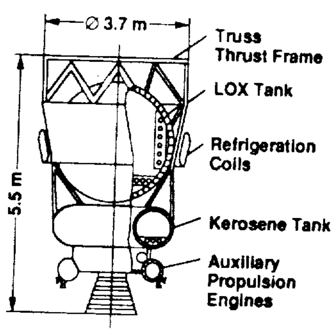
- Glavkosmos diagrams of ENERGIA with its planned cargo container, which will be 42m long & 6.7m in dia. The configuration at left, with the RCS stage alone, is for low Earth orbit missions, with a payload up to 35m long. With the EUS alone, a 23.5m payload can be sent to GEO, lunar libration points or lunar orbit. With both upper-stage motors (right) a 19.5m payload can be accomodated, primarily for planetary orbit or lander missions. Maximum cargo weight (including upper stages) is 93t. Maximum payload dia in all cases is 5.5m. Gross lift-off mass is given as 2,400 tonnes. (All drawings: courtesy of Glavkosmos/Space Commerce Corp joint venture)

Ref: Space Markets 1/1990

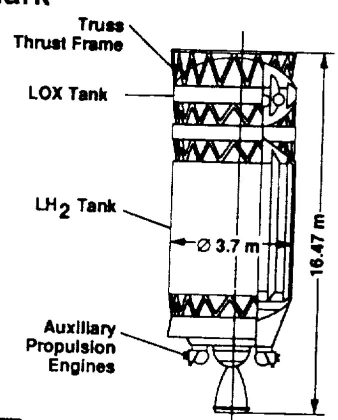
ENERGIA Cargo Module Propulsion

(Space Markets, 1/90; Credit Glavkosmos/Space Commerce Corp.)

ENERGIA's Next Stage, P.S. Clark



- RCS
  - Retro & correction stage O_2 /kerosene propellants
  - Propulsion could be Proton Block D/DM 4th stage
  - For PL to LEO & AS interorbit tug to 1,500 km



	RCS	EUS
Dry mass, tonnes	Approximately 2	Approximately 7[1]
Maximum useful propellant mass (tonnes)	15	70
Main engine maximum vacuum thrust (kN)	85	100[2]
Main engine specific impulse (s)	Approximately 352[3]	Approximately 490[4]
Maximum number of engine starts	7	10
Maximum engine operating life in space	2 yr	4 days

- Notes: [1] Estimate (see text); [2] Engine can be throttled back to 75kN
  [3] Figure derived from apparently similar Proton DM stage;
  [4] Figure estimated from performance requirements

Ref: *Space Markets, January 1990*

- EUS
  - ENERGIA upper stage O_2/H_2 propellants
  - For PL to high orbit; geostat & transplanetary

Rockwell International

EUROPEAN AND OTHER TECHNOLOGY